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Principal economic effects of cormorant predation on catfish farms

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Abstract

Substantial economic losses of farmed catfish to fish-eating birds such as the double-crested cormorant, *Phalacrocorax auritus*, continue to be reported on U.S. catfish farms. An economic analysis was conducted of the on-farm effects of both the increased expenditures to scare fish-eating birds from catfish farms and of the value of the catfish that were consumed by cormorants. A survey was conducted of U.S. catfish farmers in the Delta region of Mississippi and Arkansas, to obtain farm-level data on expenditures to scare birds. Estimations of the lost revenue from catfish consumed by cormorants were developed from a concurrent study on cormorant distribution, abundance, and diet in the region. The economic effects of bird predation in terms of both fish consumption and management costs were evaluated across three farm sizes and nine catfish production practices. Catfish farmers spent on average \$704/ha ± \$394/ha to scare birds, making bird-scaring costs one of the top five costs of raising catfish. The greatest cost components of scaring birds were manpower (39% of all bird-scaring costs) and the variable and fixed costs of trucks used to scare birds (34% of all bird-scaring costs). Losses were greater on hybrid than channel catfish fingerling ponds.

Industry-wide, the value of catfish losses averaged $47.2 million (range of $25.8–$65.4 million). Total direct economic effects (including both the increased costs to scare birds and the revenue lost from fish consumed by cormorants despite bird-scaring attempts) averaged $64.7 million (ranging from $33.5 to $92.6 million). Profitability improved by 4% to 23% across the farm size/production strategies analyzed upon removal of the economic effects from bird predation, with greater effects occurring on smaller-scale farms. One-third of the farm size and production scenarios analyzed changed from being unprofitable to showing a profit in the absence of such negative economic effects associated with bird depredation. Overall, the combined effects of increased farm expenditures to scare birds from farms and the value of the catfish lost to predation by cormorants caused substantial negative economic effects on catfish farms.

KEYWORDS

catfish losses, cormorant predation, costs to scare birds, economics of bird predation, economics of catfish

1 | INTRODUCTION

Published scientific reports of farmed catfish[1] losses to predation by double-crested cormorants, *Phalacrocorax auritus*, date back to at least 1992 (Stickley, Warrick, & Glahn, 1992). Cormorants typically arrive at catfish farms in the fall and most leave in late spring, although some number of cormorants remain in catfish farming areas year-round (Dorr, Hatch, & Weseloh, 2014). The primary feeding period on catfish ponds typically occurs from October to April. While cormorant predation on catfish ponds has been an on-going problem for the past 30 years (Dorr, Hanson-Dorr, DeVault, Barras, & Guillaumet, 2014), catfish farmers recently have reported increased cormorant depredation and corresponding losses of catfish to predation by cormorants. In response, the Industry Advisory Council of the Southern Regional Aquaculture Center prioritized funding for a study to re-assess economic effects of predation on U.S. catfish farms by cormorants with improved loss estimation methods and a more comprehensive economic analysis approach.

Previous studies have considered various characteristics of cormorant populations (Dorr, Burger, Barras, & Godwin, 2012a, 2012b; Dorr, Hanson-Dorr, et al., 2014; Glahn, Reinhold, & Sloan, 2000; Glahn & Stickley, 1995) in relation to depredation of catfish aquaculture and measured catfish consumption by birds under controlled experimental conditions (Dorr & Engle, 2015; Glahn & Dorr, 2002). Cormorants were estimated to consume about 4% of the weight of catfish in a given pond in 1995 (Glahn & Brugger, 1995), but by 2002, Glahn, Werner, Hanson, and Engle (2002) estimated that catfish yields could be reduced by 11–14% of gross pond yields from cormorant predation. In 1989, the annual value of catfish losses to cormorants was an estimated $3.3 million (Stickley & Andrews, 1989), in the Delta region of MS but estimates of industry-wide losses increased to $12 million for all fish-eating birds by 1997 (Wywialowski, 1999). Dorr et al. (2012a) estimated losses from cormorant predation in the

Delta region of MS alone at $5.6–$12 million annually. We noted that all these estimates were for farm-level losses of catfish and did not include other costs such as bird control efforts.

There have been a few previous attempts to identify expenditures by catfish farmers to scare birds from their farms. Stickley and Andrews (1989) reported estimates of 2.6 hr of time spent per day for an annual cost of $7,400 per farm, or an industry-wide total bird-scaring cost of $2.1 million per year. Littauer, Glahn, Reinhold, and Brunson (1997), in a hypothetical estimation, reported bird-scaring costs of approximately $132 per day. In 1999, Wywialowski (1999) reported expenditures per catfish farm of $6,504 ± $731 per farm, for an industry-wide expenditure of more than $5 million.

Most of the estimates of expenditures and farm losses from bird predation are more than 15 years old and improved estimation methods have become available. Moreover, the catfish industry has undergone substantial changes in management practices that have resulted in cost structures substantially different from those in previous years (Kumar et al., 2018; Kumar & Engle, 2017; Kumar, Engle, & Tucker, 2016). Improved cost analysis tools have been developed that reflect current cost structures and provide a basis for improved estimates of various types of effects on the economics of catfish production.

Thus, the goal of this study was to use improved estimation methods and more comprehensive economic approaches to examine the economic effects of catfish predation by cormorants. Specific study objectives were: (a) to measure 2018 costs on catfish farms of efforts to scare birds from farms; (b) estimate value of catfish lost to cormorant predation on catfish; and (c) assess the total economic effects from cormorant predation on catfish farms.

2 | METHODS

Four economic effects of predation by fish-eating birds were measured on catfish farms in the Mississippi River Delta region (Deltaic region of AR and MS). The first component measured the time and expense associated with efforts to scare birds from catfish farms. Second, we evaluated the lost sales revenue to catfish farms from fish losses due directly to predation by birds. Thirdly, the combined effects of increased costs and reduced yields on breakeven price (cost of production in $/kg of catfish) were analyzed for 27 catfish farm size and production scenarios. Finally, total economic impact, including indirect and induced effects industry-wide, was estimated.

This economic analysis was a part of a broader project that included study of the distribution and abundance, food habits, and bioenergetics modeling of double-crested cormorants that over winter (October–April) in the Mississippi Delta. Details can be found in Christie (2019). Briefly, the data on catfish losses as a result of cormorant predation were collected from aerial surveys every 2 weeks (October–April) of all known active cormorant night roosts, collections of cormorants (n = 728) from random samples of active night roosts in the Mississippi Delta and aerial surveys every 2 weeks (October–April) over catfish ponds. Active night roosts included 85 in Year 1 and 79 in Year 2 of the survey. For the aerial pond surveys, the sampling frame consisted of 2,772 km^2 that represented 73% of the total water surface area of the Mississippi Delta. Using a random cluster sampling method adapted from Dorr, Burger, and Barras (2008), 136 clusters of catfish ponds were identified, with 30% (41 clusters of ponds) selected randomly to be surveyed. In all, aerial surveys were conducted over 750 catfish ponds in Year 1 and 856 ponds in Year 2.

Data to measure farm-level costs of scaring birds were collected by surveying catfish farmers in the Mississippi River Delta. A questionnaire was developed, reviewed by researchers and extension personnel familiar with the catfish industry, revised, and e-mailed to catfish farmers in the study area described by Christie (2019) in the Mississippi River Delta, with an overall response rate of 88%. Follow-up telephone calls and personal visits to farms were made as necessary. Data were collected on purchases of firearms, ammunition, pyrotechnics, optics, eye and ear protection, exclusion devices, levee repairs, gravel, and expenses of trucks and drivers.

Data were coded, entered into spreadsheets and costs summed within cost categories that included: manpower, usage of trucks and other vehicles (fuel, repairs and maintenance, and annual depreciation), levee repair and maintenance (including gravel purchases to maintain all levees passable to chase birds), firearms and ammunition (including shipping), and bird-scaring devices (pyrotechnics, optics, eye and ear protection, and exclusion devices). Total bird-scaring costs were then summed for each farm and divided by the total number of hectares of water surface area in production that year to obtain a bird-scaring cost per hectare for each farm. Data were sorted into groups based on whether the farm raised primarily fingerlings (classified as a hatchery) or foodfish (classified as a growout farm) and per-ha scaring costs between hatcheries and growout farms were compared with a Student's *t* test. Data were further sorted by farm size and bird-scaring costs graphed by farm size.

Catfish losses from consumption by cormorants were used to estimate the lost revenue effects. Thus, the lost revenue estimated in this analysis reflects losses only from consumption of catfish by cormorants and does not include losses to any other type of predator. To do so, data from aerial surveys of cormorant roosts and catfish ponds combined with collections of birds for examination of gut contents were collected over two winters (October–April) 2016–2017 and 2017–2018. Details of the methods and results of consumption of catfish biomass, numbers of fish consumed, and the depredation impact (in kg/ha) are in Christie (2019). In addition to aerial surveys, farmers were interviewed to identify which ponds were in production of channel or hybrid fingerlings and foodfish and whether foodfish production was in single- or multiple-batch or in split-pond systems. Briefly, in the U.S. catfish industry, channel catfish are raised in single- or multiple-batches in which single-batch management involves a single size class of fish stocked typically at 12,350 or 14,820 fish per ha with approximately 3.68–4.42 kW/ha of aeration; or at 19,760 fish per ha with 12.15 kW/ha of aeration. Multiple-batch management systems typically involve ponds with more than one size class of fish at one time and are typically stocked at 14,820 or 19,760 fish per ha (aeration rates of 1.85–6.62 kW/ha of aeration). Hybrid catfish are raised in single-batch at 14,820 fish/ha (aeration rates of 4.25 kW/ha); or at 19,760 fish/ha or 24,700 fish/ha (with aeration rates of 13.44–13.63 kW/ha) or at 32,110 fish/ha in split pond systems (average aeration rate of 7.19 kW/ha). Split ponds are intensive systems in which the fish are partitioned in one section of the pond with the larger portion serving as a waste treatment area. Additional detail on common catfish management systems can be found in Kumar, Engle, Hegde, and van Senten (2020).

The estimated fish losses from Christie (2019) showed that the kg/ha lost because of cormorants differed between ponds used to produce channel catfish fingerlings and ponds producing hybrid catfish fingerlings (Figure 1). Thus, values of fingerlings lost were calculated separately for channel and hybrid fingerlings. For each group of fingerlings, the low, average, and high values of fingerlings lost reported by Christie (2019) were averaged across the

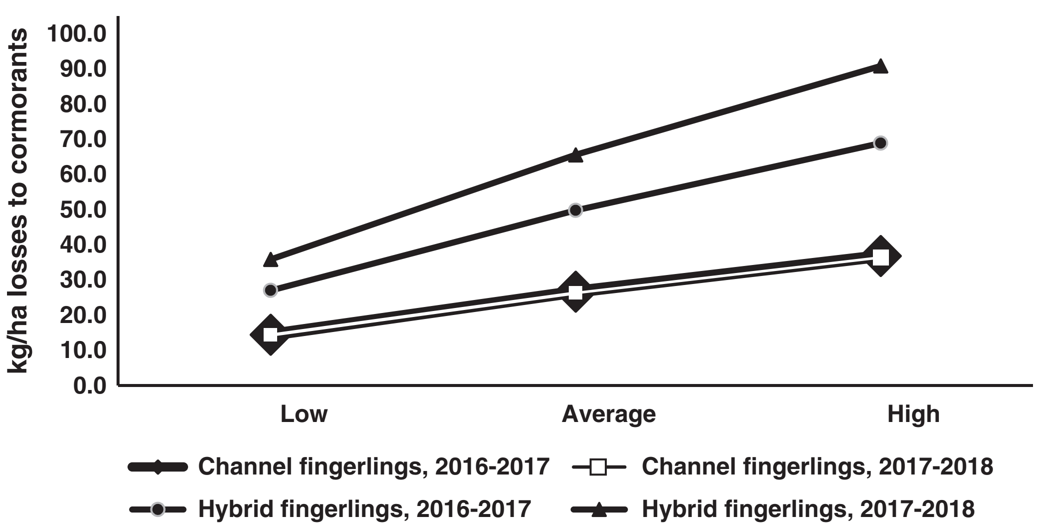


FIGURE 1 Fish losses (kg/ha) of channel and hybrid catfish fingerlings. Note that the two channel catfish fingerling lines are nearly identical with lines super-imposed

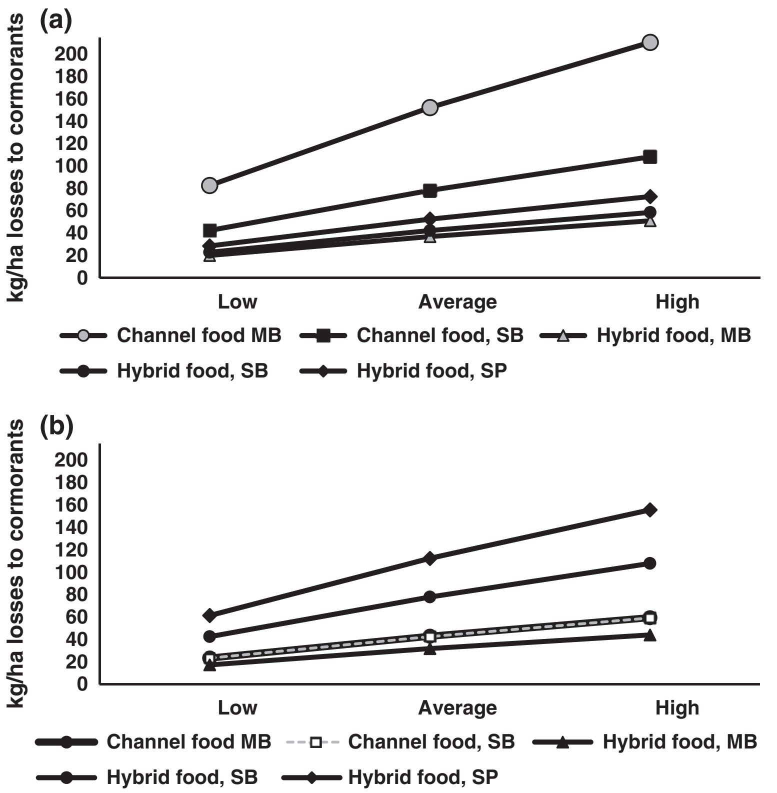


FIGURE 2 Annual variability in fish losses (kg/ha) between various catfish production systems for catfish in: (a) 2016–2017; and (b) 2017–2018. MB, multiple batch; SB, single batch; SP, split pond

2 years of data collected. Mean stocking sizes and prices/cm of channel and hybrid catfish from Kumar et al. (2020), length-weight relationships from Steeby (1995) for channel catfish fingerlings, and Brown, Mischke, and Roy (2016) for hybrid catfish fingerlings were applied to the mean fingerling losses from Christie (2019) to calculate the dollar value (per ha) of channel and hybrid catfish fingerlings lost to cormorants.

Among the various foodfish production systems, there were no clear differences in predation because of type of production system, primarily because of variability in cormorant depredation. For example, in 2016–2017, the greatest catfish losses (in kg/ha) to cormorants were those of multiple- and single-batch of channel catfish (Figure 2a), but in 2017–2018, greatest losses (in kg/ha) occurred with hybrid catfish in split ponds and in single-batch production (Figure 2b).

A weighted average of the number of fish consumed by cormorants in foodfish ponds from Christie (2019) was calculated based on the proportion of hectares in each production system as reported by Christie (2019). The fish losses from foodfish ponds, however, were primarily of fingerlings/stockers. Losses of fish stocked in growout production reduce the stocking density and the subsequent number of market-sized fish that can be harvested and sold and therefore differ in loss estimates as, unlike fingerling ponds, the loss is not realized until harvest.

To estimate the effect on foodfish sales revenue, 27 comprehensive catfish enterprise budgets were used (Kumar et al., 2020). The production and management strategies analyzed were representative of those commonly used in the U.S. catfish industry (for details, see Kumar et al., 2020) and included: channel catfish in multiple-batch production stocked at either 14,820 fish/ha or 19,760 fish/ha (aeration rates of 1.85–6.62 kW/ha); channel catfish in single-batch production stocked at either 12,350 fish/ha or 14,820 fish/ha (aeration rates of 3.68–4.42 kW/ha) or at 19,760 fish/ha with higher aeration rates (12.15 kW/ha); hybrid catfish production in single batch at stocking rates of 14,820 fish/ha (aeration rates of 4.25 kW/ha) or at 19,760 fish/ha or 24,700 fish/ha with greater aeration rates (13.44–13.63 kW/ha); and hybrid catfish production in split ponds stocked at 32,110 fish/ha (average aeration rate of 7.19 kW/ha). Three farm sizes (32, 124, and 592 ha) were included in the analysis, for a total of 27 comprehensive enterprise budget scenarios. The base budgets represent the status quo on commercial catfish farms in which farmers spend time and money to attempt to scare birds, but despite such efforts, cormorants continue to consume catfish.

Survival rates in each budget were adjusted based on the numbers of catfish fingerlings/stockers consumed by cormorants as described in Christie (2019). Lost sales revenue (kg/ha lost) of foodfish was calculated by applying an average market weight of 0.68 kg for channel catfish and 0.79 kg for hybrid catfish and a weighted average kg/ha calculated based on the relative proportions of ha in the various production strategies from Christie (2019). The foodfish lost (kg/ha) for each scenario were multiplied by the average market price of catfish ($2.20/kg) to obtain the value of foodfish sales revenue lost ($/ha) because of cormorant predation. The potential for compensatory gain from reduced fingerling survival because of bird predation was considered, but the percent of predation was less than the threshold identified by Dorr and Engle (2015) to trigger compensatory gain. While various studies have documented increased growth of catfish stocked at lower densities in single-batch production systems (Southworth, Engle, & Stone, 2006), Dorr and Engle (2015) showed that compensatory growth became evident only at predation levels above 30%, which exceeded the percentage levels of predation by cormorants measured in this study.

To calculate total industry-wide values of lost sales revenue from fingerling and foodfish ponds, total hectares in production of each catfish life stage were multiplied by the $/ha losses. The total ha in broodstock, fingerlings, and foodfish catfish production from USDA-NASS (2016, 2017, 2018, 2019) were multiplied by the value of fish losses in $/ha for channel and hybrid fingerlings and market-sized catfish foodfish, respectively, and the values summed.

The third economic effect of fish-eating birds analyzed in this study was the effect on the breakeven price (cost of production in $/kg). Breakeven price above total cost was selected because it includes both effects on variable costs (such as increased fuel costs of trucks used to scare birds) and fixed costs (such as annual depreciation costs of trucks used to scare birds). In addition, fixed costs per kg of fish sold increased with lower yields because there are fewer kg of fish across which to spread annual fixed costs. The capital-intensive nature of catfish farming results in economies of scale under which greater yields reduce the annual fixed costs per kg. Catfish losses because of fish-eating birds reduce overall yields, increase annual fixed costs, and increase the breakeven price of catfish. To remove the effects of bird-scaring costs and reduced fish yields, the bird-scaring costs were subtracted out of each of the 27 catfish production budgets, and the estimated kg/ha of foodfish catfish lost were added to the mean yields in each budget. Budgets were structured with formulas that adjusted yield-dependent variable costs (i.e., the quantity of feed) to different mean yields. The resulting breakeven prices above total costs were recorded.

In addition to the direct revenue losses from fish-eating birds, indirect and induced effects were also estimated. The economic output multiplier for catfish production from Kaliba and Engle (2003) (1.5) was multiplied times the total value of fish losses to estimate the total economic effects in the Mississippi Delta region.

3 | RESULTS

Bird-scaring expenses (mean ± *SD*) by catfish farmers averaged $704 ± 394/ha (range of $42/ha–$1,618/ha) (Table 1). The costs of attempting to scare birds from catfish farms have become a major cost of production, constituting one of the top five production costs for all scenarios analyzed. Of the costs reported by catfish farmers, manpower composed 39% of the costs of scaring birds, followed by 34% for the costs of truck usage, 18% for levee upkeep, firearms and ammunition 7%, and only 2% of costs were for pyrotechnics and exclusion devices (Figure 3). Farms reported using one truck and one person for 155 ± 44 ha of water surface area; for 7.0 ± 6.9 months per person for 45 ± 45 hr/week to scare birds. Bird-scaring costs were not significantly different ($p > .05$) on foodfish farms compared to hatchery farms.

Figure 4 appears to demonstrate a generally declining trend in per-ha bird-scaring costs as farm size increased up to ~202 ha. The costs were, however, highly variable (R^2 = 0.19) with few observations from very large farm

TABLE 1 Mean costs ($/ha) of scaring birds on commercial catfish farms, compared to other major costs modeled for a representative 124-ha commercial catfish farms, Mississippi Delta, 2018

Management strategy[a]	Feed	Fingerlings	Electricity	Seining and hauling	Labor	Scaring birds
CC-14.8K MB	$4,364	$1,334	$662	$556	$494	$704 ± $394
CC-19.8K MB	$7,654	$1,994	$1,076	$994	$530	$704 ± $394
CC-12.4K SB	$4,580	$1,414	$927	$587	$494	$704 ± $394
CC-14.8K SB	$6,270	$1,660	$927	$794	$494	$704 ± $394
CC-19.8K SB-IA	$8,339	$2,396	$1,424	$1,071	$566	$704 ± $394
HY-14.8K SB	$7,220	$2,391	$994	$897	$494	$704 ± $394
HY-19.8K SB-IA	$12,165	$3,457	$1,882	$1,423	$637	$704 ± $394
HY-24.7K SB-IA	$13,464	$5,219	$1,882	$1,649	$637	$704 ± $394
HY-32.1K SP	$17,270	$6,529	$2,319	$2,083	$637	$704 ± $394

[a]14.8K, 19.8K, 12.4K, 14.8K, 19.8K, 24.7K, 32.1K = stocking rates of 14,800/ha; 19,800/ha; 12,400/ha; 14,800/ha; 24,700/ha, and 32,100/ha.
Abbreviations: CC, channel catfish; HY, hybrid catfish; IA, intensively aerated; MB, multiple batch; SB, single batch; SP, split pond.

FIGURE 3 Relative proportions of cost components of scaring fish-eating birds on catfish farms, Mississippi Delta, 2018

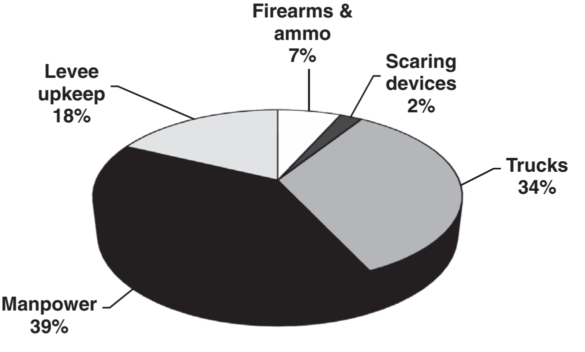
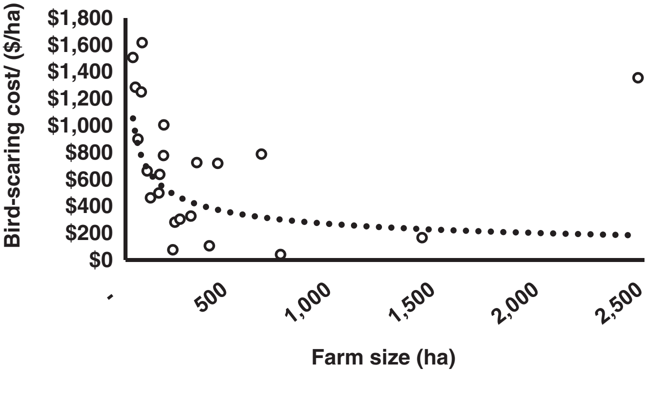


FIGURE 4 Farm size versus bird-scaring cost, Mississippi Delta, 2018



sizes. It is notable that the largest farm size in the study also reported bird-scaring costs that were among the highest, indicating that the per-ha cost of scaring birds can also be quite high on large farms. Bird pressure on farms is influenced by many variables, including distance from roost sites (Burr, 2019).

Table 2 shows the value of lost revenue from catfish farms industry-wide for three depredation levels (low, average, and high) for channel catfish fingerling, hybrid catfish fingerling, and market-sized foodfish production. Industry-wide, the value of all fish sales revenue losses averaged $47.2 million (range of $25.8–$65.4 million). Of these, 98.6% were losses of foodfish that averaged $46.6 million (ranging from $25.4 to $64.5 million in years with heavy predation). The value of hybrid catfish fingerlings lost (averaging $560,440) was nearly seven times greater than that of the value of channel catfish fingerling losses ($81,189) because of the greater kg/ha consumed by birds combined with the greater total production area of hybrid as compared to channel catfish fingerlings. The economic effects of hybrid catfish fingerling losses were further compounded by the greater price per cm of hybrid catfish fingerlings compared to the per-cm price of channel catfish fingerlings.

Table 3 combines the increased costs of scaring birds with the value of fish losses. Summing the effects across life stages, the total direct economic effects on the U.S. catfish industry from cormorant predation averaged $64.7 million (ranging from $33.5 to $92.6 million), depending on bird predation levels in any given year.

Effects on breakeven prices (costs of production, measured as $/kg) for nine production strategies on three farm sizes are shown in Table 4. Values reflect effects of both bird-scaring costs and lost sales revenue to fish consumed by cormorants. Breakeven prices above total costs for the base case reflected the economies of scale discussed by

TABLE 2 Industry-wide value of losses of catfish to cormorants by life stage, U.S. catfish industry, Mississippi Delta, 2018

Life stage	Low	Average	High
Channel catfish fingerlings	$44,148	$81,189	$112,216
Hybrid catfish fingerlings	$305,576	$560,440	$775,860
Market-sized foodfish	$25,402,549	$46,582,632	$64,465,562
Total	$25,752,274	$47,224,261	$65,353,638

TABLE 3 Industry-wide total direct economic effects of bird predation on catfish farms, U.S. catfish industry, Mississippi Delta, 2018

Life stage	Bird-scaring costs	Value of fish losses	Total direct economic effects
Fingerlings			
Channels			
Low	$352,762	$44,148	$396,910
Average	$797,914	$81,189	$879,103
High	$1,243,066	$112,216	$1,355,282
Hybrids			
Low	$705,524	$305,576	$1,011,100
Average	$1,595,828	$560,440	$2,156,268
High	$2,486,132	$775,860	$3,261,992
Foodsize			
Low	$6,667,079	$25,402,549	$32,069,628
Average	$15,080,297	$46,582,632	$61,662,929
High	$23,493,516	$64,465,562	$87,959,078
Total			
Low	$7,725,365	$25,752,274	$33,477,639
Average	$17,474,039	$47,224,261	$64,698,300
High	$27,222,714	$65,353,638	$92,576,352

Kumar et al. (2020) as well as differing levels of profitability among the various production systems commonly practiced in the U.S. catfish industry.

TABLE 4 Effect on breakeven price above total costs because of fish-eating birds, losses and costs of scaring, modeled on three representative catfish farm sizes (32-ha, 124-ha, and 592-ha), for three predation levels (average, low, and high), Mississippi Delta, 2018

		Cormorant predation level		
Farm size/production strategy[a]	**Base**	**Average**	**High**	**Low**
32-ha				
CC-14.8K MB	2.71	2.10	2.32	1.94
CC-19.8K MB	2.18	1.90	2.02	1.82
CC-12.4K SB	2.67	2.31	2.46	2.19
CC-14.8K SB	2.32	2.08	2.18	2.00
CC-19.8K SB-IA	2.27	2.09	2.16	2.03
HY-14.8K SB	2.29	2.08	2.17	2.01
HY-19.8K SB-IA	2.23	2.09	2.15	2.05
HY-24.7K SB-IA	2.16	2.05	2.10	2.01
HY-32.1K SP	2.07	1.95	2.00	1.91
124-ha				
CC-14.8K MB	2.47	1.96	2.17	1.82
CC-19.8K MB	2.07	1.80	1.91	1.72
CC-12.4K SB	2.51	2.16	2.31	2.06
CC-14.8K SB	2.18	1.97	2.06	1.89
CC-19.8K SB-IA	2.16	2.00	2.08	1.94
HY-14.8K SB	2.18	1.98	2.07	1.91
HY-19.8K SB-IA	2.14	2.00	2.06	1.96
HY-24.7K SB-IA	2.07	1.97	2.02	1.93
HY-32.1K SP	2.01	1.93	1.96	1.90
592-ha				
CC-14.8K MB	2.36	1.86	2.06	1.73
CC-19.8K MB	1.98	1.72	1.83	1.65
CC-12.4K SB	2.38	2.06	2.19	1.96
CC-14.8K SB	2.09	1.88	1.97	1.81
CC-19.8K SB-IA	2.07	1.92	1.99	1.86
HY-14.8K SB	2.09	1.91	1.99	1.84
HY-19.8K SB-IA	2.07	1.94	2.00	1.90
HY-24.7K SB-IA	2.03	1.92	1.96	1.88
HY-32.1K SP	1.96	1.85	1.90	1.81

Note: Values in $/kg

Abbreviations: CC, channel catfish; HY, hybrid catfish; IA, intensively aerated; MB, multiple batch; SB, single batch; SP, split pond.

[a]14.8 K, 19.8 K, 12.4 K, 14.8 K, 19.8 K, 24.7 K, 32.1 K = stocking rates of 14,800/ha; 19,800/ha; 12,400/ha; 14,800/ha; 24,700/ha, and 32,100/ha.

Figure 5a shows that six of the nine production scenarios on the smallest farm size were not profitable and two of nine on the medium and large farm sizes were not profitable under the base conditions (continued fish losses in addition to bird-scaring expenditures). When the negative economic effects from bird predation were removed, only one of the production scenarios on the smallest farm size was not profitable; all other farm size/production scenarios were profitable, at average market prices (Figure 5b).

Removing the negative effects of birds improved profitability across all scenarios. The percentage decrease in breakeven price above total costs from removing the negative economic effects of bird predation ranged from 4 to

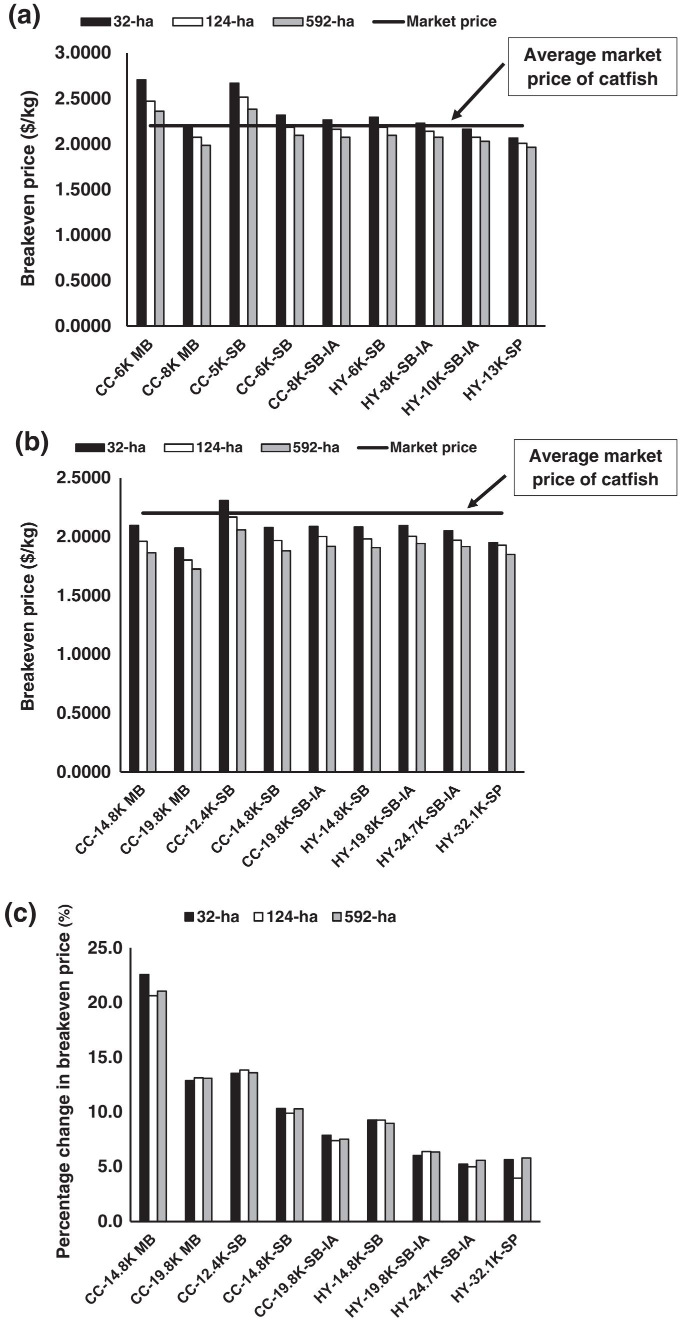


FIGURE 5 Breakeven prices above total costs for: (a) base scenario; (b) without economic effects of bird losses, average level of predation; and (c) percentage change in breakeven price above total costs without negative economic effects from birds. CC, channel catfish; HY, hybrid catfish; IA, intensively aerated; MB, multiple batch; SB, single batch; SP, split pond; 14.8K, 19.8K, 12.4K, 14.8K, 19.8K, 24.7K, 32.1K = stocking rates of 14,800/ha; 19,800/ha; 12,400/ha; 14,800/ha; 24,700/ha, and 32,100/ha)

TABLE 5 Economic impact of catfish losses because of cormorants, U.S. catfish industry, Mississippi Delta, 2018

Cormorant predation level	Economic output (multiplier = 1.5[a])
Low	$38,628,411
Average	$70,836,391
High	$98,030,457

[a]Kaliba and Engle (2003).

23%, with the greatest percentage improvements observed on the smallest farm scenarios (Figure 5c). Improvements in profitability reduce financial risk on catfish farms both by reducing costs of production and providing a greater margin of safety in the event of market price decreases. With lower costs of production, farms remain profitable at lower market prices, reducing market price risk.

To estimate the industry-wide economic impact associated with the value of fish lost to cormorants, the economic multiplier for total economic output (1.5) from Kaliba and Engle (2003) was applied to the values of total fish losses. Effects on total economic output averaged $70.8 million (ranging from $38.6 to $98.0 million) (Table 5).

4 | DISCUSSION

Catfish farmers expend time and money to attempt to scare fish-eating birds from farms to reduce fish losses. Nevertheless, despite intense efforts to scare birds, cormorants continue to successfully feed on farmed catfish. This study measured current economic effects of cormorant predation on farm-raised catfish by: (a) measuring on-farm costs of bird-scaring by catfish farmers; (b) estimating the value of fingerling/stockers consumed by cormorants on hatcheries; (c) estimating the value of the lost foodfish sales revenue from predation by cormorants; (d) estimating total direct economic effects; and (e) estimating multiplier-driven indirect economic effects from cormorant predation. This study collected data only on depredation losses from double-crested cormorants, but other bird species also consume catfish. Thus, the fish losses in this study are underestimated, although cormorants are considered to be responsible for a large portion of catfish losses. Moreover, birds have been shown to be vectors of commercially important disease pathogens (Cunningham et al., 2019; Jubirt et al., 2015). Thus, the total revenue losses because of fish-eating birds may be somewhat underestimated in this study. In addition, the estimate of industry-wide economic losses was based on the assumption that cormorant use of catfish aquaculture is similar across production regions. Given observations and comments from catfish farmers in other regions, that assumption seems reasonable, but additional studies to measure losses to cormorants in other regions are warranted.

Expenditures by catfish farmers to scare birds appear to have increased over time. Table 6 reports values from earlier studies that were adjusted[2] to 2018 dollars (United States) and standardized with the 2018 market price of catfish ($2.20/kg) (Table 6). The earliest reported farm expenditures to scare birds were $120/ha in 1989 (Stickley & Andrews, 1989), increased to $188/ha in 1999 (Wywialowski, 1999), and to $704/ha in the present study. These studies span more than 30 years and suggest fairly dramatic increases in the efforts and expenditures by catfish farmers to scare fish-eating birds from their farms, although the more comprehensive approaches used in this study may have resulted in more complete cost estimates than those of previous studies.

Christie (2019) reported that the average depredation impacts measured, of 45 kg/ha, were nearly double those reported in 1995 of 24 kg/ha (Glahn & Brugger, 1995). Improved loss estimation methods may, at least in part, account for this increase (Christie, 2019). Recent research suggests that the cormorant density averaged across all catfish ponds from 2015 to 2018 is similar to estimates from 2000 to 2003 (Burr, Avery, Street, Strickland, & Dorr, in press). Production practices have changed over time as well with a shift to hybrid catfish and intensive production practices with higher stocking densities, which may influence overall loss estimates. Regardless, consumption

TABLE 6 Comparison of historical estimates of negative economic effects on catfish farms of fish-eating bird predation, Mississippi Delta, 2018

Year	Bird-scaring costs ($/ha)	Value of fish losses ($/ha)
1989[a]	120	n.a.[b]
1992[c]	n.a.[b]	236
1995[d]	n.a.[b]	287
1999[e]	188	280
2002[f]	n.a.[b]	1,470
2020[g]	704	1,517–3,162

Note: Values from the various studies were adjusted to 2018 U.S. dollars using the Producers' Price Index; the market price of catfish used to assign a value of fish losses was adjusted to the study price of $2.20/kg.
[a]Stickley and Andrews (1989).
[b]Did not measure in study.
[c]Stickley et al. (1992).
[d]Glahn and Brugger (1995).
[e]Wywialowski (1999).
[f]Glahn et al. (2002).
[g]Engle et al. (current study).

per ha of catfish by cormorants appears to be as much and possibly greater than what has been estimated in the past. The estimated value of fish losses has similarly increased over time. Values from previous studies were standardized using the 2018 market price of catfish ($2.20/kg) (Table 6). Estimated values of fish losses to cormorants increased from $236/ha (Stickley et al., 1992) in 1992 to $280/ha in 1999 (Wywialowski, 1999), to $1,470/ha in 2002 (Glahn et al., 2002). The estimated values of fish losses in this current study ranged from $1,517/ha to $3,162/ha (based on average depredation levels) and varied according to the farm size/production management strategy. The more comprehensive approaches used in this study to estimate the value of fish losses in different management strategies on different farm sizes may have contributed to the increased cost estimates. Moreover, this study combined the value of fish losses with those of bird management costs to estimate direct economic effects, but unlike previous studies also used an economic multiplier to examine indirect economic effects not considered in previous studies.

The data used in this study do not include observations of estimated fish losses in the absence of efforts to scare birds from cormorant ponds. No commercial farmer can afford to take the risk of potentially devastating losses, and participants in the study were not asked to allow those losses to occur simply to generate such data. Hegde and Kumar (2019), however, presented data from large, commercial-sized (ranging in size from 0.8 to 1.6 ha) research ponds for a time period during which the research facility was unable to scare birds because of the inability to obtain the necessary depredation permit. Large numbers of cormorants were observed for a period of time (January–March) on the research ponds, following which catfish feeding rates decreased. When the cormorants left the facility, ponds were seined, catfish were weighed back into the ponds, and the mortality to cormorants estimated based on Kumar and Engle (2010). Catfish mortality rates ranged from 35 to 60%, compared to typical mortality rates in those ponds of 21% to 22%.

Such losses from cormorant predation in the absence of depredation permits would result in substantial losses to a commercial catfish farm (Table 7). For a 124-ha representative catfish farm with channel catfish (stocked at 19,760/ha with intensive aeration) and hybrid catfish (stocked at 24,700/ha with intensive aeration), net returns would decrease by approximately $396,393/farm and approximately $467,788/farm, respectively, for each 10% decrease in survival.

Researchers involved in the above study observed greater concentrations of cormorants on more heavily stocked ponds (Hegde & Kumar, 2019). If fish-eating birds generally are attracted to higher-density ponds, the value of lost foodfish sales revenue reported in this study is likely under-estimated. The trend of increased intensification

TABLE 7 Effect on net returns from cormorant predation on catfish on commercial-scale research ponds when depredation permits were not allowed

Scenario	Production scenario	
	Channel catfish, stocked at 19,760/ha, intensive aeration	Hybrid catfish, stocked at 24,700/ha, intensive aeration
Base case, survival	65%	85%
Net returns ($/farm)		
Base case	$67,554	$280,415
60% survival	−$124,373	−$869,485
50% survival	−$520,766	−$1,337,274
40% survival	−$917,159	−$1,805,062
Decrease in net returns per 10% decrease in survival	−$396,393	−$467,788

Source: Hegde and Kumar (2019).

in the catfish industry indicates that additional work is warranted to determine whether fish-eating birds are attracted in greater numbers to higher-density ponds.

While not quantified in this study, the problem of depredating birds was reported by respondents to lead to increased inefficiencies in how farms are managed. One respondent said, "We have changed how we manage our entire farm due to birds, not efficiency; we schedule seining of ponds with the greatest bird pressure first; anyone going into town drives by ponds with birds on the way in and comes back a different way."

The fish consumption data estimated in this project demonstrated a great deal of variability. Some of the variability in depredation levels was because of annual fluctuations in the numbers of birds arriving at catfish farms and the timing of their arrival. Another source of variation is the distance that catfish farms are located from bird roosting sites. Moreover, Christie (2019) found that cormorants moved their roost sites closer to catfish farms in January and February. Burr et al. (in press) found that not only are there more cormorants in the delta region of MS during late January to April, but that they use aquaculture more than expected given its availability. We also note that the cormorant diet data from Christie (2019) was collected from cormorants in the MS and AR delta region and extrapolated to the industry for industry-wide estimates. Cormorants are clearly a concern industry-wide (Wywialowski, 1999) and this area represents a large proportion of aquaculture production; there may be regional differences in cormorant depredation which may add to variability in the industry-wide estimates.

Such variability in bird depredation levels is, in economic terms, a source of yield risk for catfish farmers. In the absence of insurance programs, catfish farmers attempt to manage the risk of losses to bird predation by spending significant time and money to scare birds. Clearly, the risk of substantial losses likely to occur in the absence of bird-scaring efforts is too great for catfish farms, and catfish farmers are spending greater amounts of time and effort than previously to attempt to reduce this risk.

While catfish farming was established as a form of agriculture under the National Aquaculture Act, losses of catfish to federally protected avian predators are not covered under federal programs that were created to mitigate some portion of these types of losses. For example, the Livestock Indemnity Protection (LIP) covers cattle losses from attacks by avian predators, but aquaculture farms are not eligible for the LIP program. Similarly, while the Emergency Assistance for Livestock, Honeybees, and Farm-raised Fish Program (ELAP) includes "farm-raised fish" in the title, ELAP coverage is restricted to baitfish and gamefish, and catfish are excluded. Catfish are covered under the Noninsured Crop Disaster Assistance Program (NAP), but NAP covers primarily drought and flood disasters. Thus, the national efforts to protect migratory bird species, while widely successful in meeting their goals of recovering bird populations, have also created serious economic problems on catfish farms without provision of compensatory relief programs that are available to other segments of agriculture.

5 | CONCLUSIONS

Estimates of losses of catfish to double-crested cormorants in this study are nearly double previous estimates. Catfish farmers spent $704/ha ± 393/ha in 2018 to scare birds, making bird-scaring costs one of the top five costs of raising catfish. The greatest cost components of scaring birds were the manpower required (39% of all bird-scaring costs) and for trucks used to scare birds (34% of all bird-scaring costs). Greater losses were found on hybrid catfish than on channel catfish fingerling ponds. Industry-wide, the value of catfish losses averaged $47.2 million (range of $25.8–$65.4 million). Total direct losses (including both the increased costs to scare birds and the fish losses despite bird scaring attempts) averaged $64.7 million (ranging from $33.5 to $92.6 million). Profitability improved by 4–23% across the farm size/production strategies analyzed upon removal of economic effects of bird predation and resulted in all but one of the previously unprofitable farm size/production strategies becoming profitable. Overall, the combined effects of increased costs from farm expenditures and efforts to scare birds from farms and the sales revenue value of the catfish lost because of predation by cormorants caused substantial negative economic effects on catfish farms.

Project results demonstrate that farmers are spending more money and more time than previously thought in efforts to scare birds from their ponds. This information is useful for policy-makers and others to attempt to identify ways to reduce the risk and the economic damages to fish farmers from fish-eating birds.

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ENDNOTES

[1] In the United States, catfish farms predominantly raise purebred channel catfish, *Ictalurus punctatus*, but there has been increased use of the F1 hybrid of female channel catfish, *I. punctatus*, and male blue catfish, *I. furcatus*. The word “catfish” is used throughout the manuscript to refer to the fish raised in the industry.

[2] Using Producer's Price Index, from Bureau of Labor Statistics. Retrieved from www.bls.gov/ppi.

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